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NITROGEN AND SULPHUR OXIDE EMISSION REDUCTION STUDY

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OCT 27 1982

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NITROGEN AND SULPHUR OXIDE EMISSION REDUCTION STUDY

(Low NO_x Technico-Economic Study - Order no 1511967;

FC 223-131-000000-430707-0433; RN 23440-1-9119)

Prepared for CANMET by G. A. ROBB ASSOCIATES

CONCLUSIONS AND RECOMMENDATIONS:

1. The CBF Gagetown boilers are ideal for experiments aimed at reducing nitrogen oxide (NO_x) and sulphur dioxide (SO_x) emissions from pulverized coal boilers by using low NO_x burners with calcium compound injection.
2. Fully proven low NO_x pulverized coal burners are available from more than one source.
3. There is significant experience with injection of calcium compounds with low NO_x burners to reduce SO_x emissions.
4. Both technical and economic potential for this

technology appears to be good. This has been confirmed in very positive terms by the firm with the most experience and by EER.

5. The EER study provides valuable technical advice, advice on suitability of the CBF Gagetown boilers and on technology sources for low NOx burners with sorbent injections to reduce SOx. Their cost estimates are excessive and their approach to getting the job done should not be accepted. More than 1 boiler manufacturer speaks highly of their scientific capability in NOx/SOx reduction. They should be involved in an advisory capacity.

6. Material suitable for pneumatic handling should be used. For experiments involving injection without passing through the coal pulverizer, powdered material should be bought. On site pulverizing should be avoided.

7. While injection of powdered calcium compounds with tertiary and secondary air appears to offer the most potential, there should also be tests where the calcium compounds are mixed with the coal. Limestone injection should be evaluated because of low cost, but calcium hydroxide may be sufficiently more effective to justify the higher cost.

8. Steinmuller, Foster Wheeler, C. E. Canada and B&W Canada should all be asked to submit proposals on detailed designs plus firm prices on supply and installation of 2 low NOx burners on boiler no.2 with matching calcium injection systems. These 4 firms have expressed interest, provided information and attended the baseline tests.

9. The existing burner management system on boiler no. 2 appears to be adequate although arguments of suppliers should be considered. This matter requires further consideration. Complex burner management systems with many trips should be avoided because of the risk of spurious trips during tests. Management feels an oil pilot is essential at all loads to virtually eliminate the explosion risk. They have a good case because, regardless of the degree of stability of the burners, there is always risk of momentary coal feed interruption.

10. Due to tests conducted in late March 1982, there is adequate baseline test data on NOx emissions and SOx emissions without limestone injection and with limestone injection (via the coal pulverizers).

11. Coal metering at each pulveriser would be desirable if sufficiently accurate equipment is offered by those submitting bids on systems.

12. RFP's for the detailed designs and firm prices on supply and installation should be issued in spring 1982 and the equipment should be installed during the summer of 1983.

13. Havelock lime is in a position to supply suitable limestone or calcium hydroxide. Price data is in this report. They have screens and air classification equipment capable of producing limestone which will pass 100 mesh or less and a large fraction of this product is much smaller than 100 mesh. They are to determine how much there is of each size fraction. Calcium hydroxide is a minimum of 200 mesh and a large fraction is smaller.

14. Specifications should allow a maximum of initiative on the part of potential suppliers. It is anticipated that at least one supplier will be willing to guarantee 50% reductions NOx and SOx. There will be greater willingness to guarantee NOx than SOx.

15. A reduction in SOx emissions of some 40% was achieved during the baseline tests by feeding limestone into the coal before the coal pulverizer. This is interesting enough to warrant further consideration. Low NOx burners need not be expensive, however, and it seems likely that the

combined low NOx/SOx approach is best. This project and further experimenting elsewhere should bring this into focus.

16. Low NOx burners without limestone addition are commercially available at reasonable installed cost (five figures or less). The study indicates quite clearly that the real value of the Gagetown project lies in advancing combined NOx/SOx reduction technology. The terms of reference ask for an evaluation of low NOx burners without calcium addition. The conclusion is that this option would not be appropriate because of the importance of finding an alternative to wet scrubbing for the very large eastern North American high sulphur coal resource.

SUMMARY

This study deals with the application of low NOx, wall type burners with limestone injection for SOx reduction to industrial size boilers. Such boilers are also used in central or district heating plants. The tests discussed here will provide data on systems which can be scaled up for use in utility boilers.

Both NOx and SOx are major contributors to acid rain. Eastern Canadian steam coals, and a large fraction of the

coal produced in USA, contain relatively high percentages of sulphur. These sources of coal represent one of the most important potential alternatives to oil for industrial and electrical utility use in eastern Canada. Thus, the Gagetown experiments are an energy project in the sense that they should help achieve environmentally acceptable oil displacement. They should help achieve the objectives of the Environment Canada because of the need to reduce NOx/SOx emissions and the fact that limestone injection into the furnace may be accepted in cases where wet scrubbers would not.

The Gagetown project involves the installation of 2, low NOx burners and injection of sulphur absorbing limestone, calcium hydroxide or other sorbents in one of three, 70 million BTU/hr hot water boilers at CFB Gagetown. This will provide an opportunity to test and evaluate the system selected.

The interdepartmental committee responsible for the Project is comprised of G. K. Lee, EMR/CANMET, chairman; A. Bambrough, Environment Canada; W. A. Warfe, EMR/Energy Sector; Major N. Dorff, DND Ottawa; Major R. R. Lewis DND Gagetown; F. W. Pollitt (heating plant superintendent) DND Gagetown and Alex Lawson, DCL, Ottawa.

The Gagetown boilers were chosen because of a demonstrated co-operative approach by those responsible for

the operation and because the boilers are suitable.

Evaluation of burner designs is in some ways less satisfactory when a large boiler must be used. Most pulverized coal boilers are large. Few boilers as small as those at Gagetown are fired with pulverized coal. Only two low NOx burners and a relatively small limestone injection system are required to fully equip one of them.

Accurate measurement of output is easier with boilers which heat water instead of steam. The Gagetown boilers are hot water units.

A study and proposal by Energy and Environmental Research Corp. of California was used as a point of departure. That proposal envisaged dealing with a single supplier and developing a burner in the EER test facility. It has been decided that several suppliers should be considered and fully proven burners should be used. The US development program they proposed is not justified. The EER report provided valuable background information and confirmed that the Gagetown boilers are suitable for the test program.

Limestone, mixed with the coal or injected with secondary or tertiary air, calcines in the furnace. The resulting calcium oxide (lime) reacts with SO₂ in the furnace or between the furnace and the stack to form solid

sulphur compounds which can be removed with the ash. There is no sludge disposal problem as with wet scrubbers.

Low NOx burners operate at lower temperatures so when limestone is used, there is less chance of loss of lime reactivity (dead burning). The highest temperature region can be avoided by injecting the limestone with the secondary or tertiary air rather than with the primary air (the air which conveys the coal).

The case for injecting the limestone with the coal is founded on the arguments that the same pulverizer pulverizes both the coal and the limestone and that there may be more intimate mixing of the coal with the limestone. The disadvantage is the fact that the limestone calcines on passing through the highest temperature zone where there may be a reduction in the reactivity of the calcium oxide.

While the reducing combustion zone is cooled less by air than is the zone near the tip of a conventional PFC wall burner, it is cooled more by surplus fuel. It is felt that the temperature is lower than with the conventional burner. The cooling effect of the limestone on the reducing zone could be a disadvantage in terms of good combustion, particularly with less reactive coals.

An advantage over dry scrubbing is the fact that limestone is converted to calcium oxide (it is calcined) by

the furnace. With dry scrubbing, calcium oxide or other sorbent more expensive than limestone must be purchased.

As with dry scrubbing, the captured sulphur remains in the solid particulate. The "free calcining" in the furnace may be an advantage over dry scrubbing where lime or another sorbent more expensive than limestone must be used.

The Gagetown experiments should not be limited to testing with limestone. Steinmuller of Germany have achieved impressive results with calcium hydroxide. The plan is to buy the material in powdered form suitable for pneumatic handling, using equipment which can handle and store powdered limestone or calcium hydroxide.

Foster Wheeler, Babcock Wilcox Canada, Mitsubishi (the Japanese affiliate of C. E. Canada), Steinmuller, Babcock Power (U. K.) and Riley Stoker have all undertaken development work on wall type, low NOx burners.

EVALUATION OF TECHNOLOGY OPTIONS FOR NOx/SOx REDUCTION

FOSTER WHEELER

Foster Wheeler were to have been subcontractors to EER, according to the EER proposal. That would have meant their involvement in development of an unproven burner design. They now prefer to offer their fully proven

controlled flow/split flame burner. This burner has inner and outer separately controlled secondary air streams. Secondary air flow to each burner is controlled and measured using a perforated plate ring and sleeve arrangement.

They feel tertiary air ports should be avoided because cost and space limitations are a deterrents to the use of the technique.

According to Joel Vatsky, Manager of Combustion Technology, Staff Engineering Operations, Foster Wheeler is in a position to supply low NOx burners of fully proven design for boiler no. 2 at Gagetown without windbox modification or forced draft fan change. He said the windbox pressure requirement is 2 inches of water.

G. A. Robb spent several hours with Mr. Vatsky, Manager, Combustion Technology and W. D. Higdon, Emission Control Engineer, staff operations in Livingston. Mr Higdon visited the site during the EER study and during the last half of the baseline tests. Joel Vatsky visited the Canadian Combustion Lab. and met with G. K. Lee.

While Foster Wheeler have not recently experimented with limestone injection at the burner, they plan such experiments in Japan during the coming year. They are prepared to bid on a complete burner/limestone system.

They have also worked with EER in developing the EPA distributed mix low NOx burner concept.

Foster Wheeler will offer their Controlled flow /split flame (CF/SF) design with internal staging and a short flame. They feel this is the best low NOx burner available and are concerned about giving away their secrets to the competition. Tertiary air ports are not required. Dual registers control secondary air flow. The inner register is set manually then fixed during initial boiler operation. The outer register is electrically driven with "closed", "ignite" and "operate" positions. A perforated plate air hood and moveable sleeve controls secondary air flow to each burner. The split flame coal nozzle concentrates the coal into four separate streams to provide four low stoichiometric flames (70% near the throat region) with normal excess air (typically 20%) to the burner as a whole. On initial start up the inner tip of the nozzle is moved manually then fixed at optimum primary air velocity. The secondary air flow to each burner can be measured and controlled.

Foster Wheeler claim that that large burner to burner distances and tall furnaces are not required to accomodate long, lazy flames for NOx control. NOx reductions of up to 60% have been achieved.

While they have been leaders in the use of limestone

for SO₂ absorption via fluidized beds, and did some work with limestone injection into pulverized coal boilers years ago, they do not have an ongoing program and recent experience comparable with that of Steinmuller. They plan a program, probably with their Japanese affiliate. While that program will provide information before the Gagetown burners are installed, it will not likely be sufficient to assist in the preparation of a detailed design, and fixed cost proposal or with the guarantee of 50% SO₂ reduction.

BABCOCK & WILCOX CANADA LTD.

This firm has expressed a keen interest through Bruce Paley, Supervisor, Results Engineering & Development. He and another B & W engineer attended the baseline tests and provided some help. They did not stay for the limestone injection phase. We have not yet had an opportunity to discuss the Gagetown project with the top Canadian technical people nor their U. S. researchers. They have not provided us with published material.

BWC have fully proven low NO_x burners for large utility boilers. These were installed at Nantickoke with CANMET participation. Their is concern about the suitability of their proven designs for small boilers because of the long flame. They say they are working on a unit for

industrial boilers. They would require a windbox 5 feet deep and a 5 inch wg windbox pressure. Tests by G. A. Robb Associates indicate that more than 5" wg windbox pressure is available at full load air flow. The windbox, however, is less than 5 ft deep.

BWC do not have experience with limestone injection into the furnace and they seem somewhat less interested in this technology than Steinmuller and C E. They should be invited to bid but the lack of experience with limestone injection could be a problem. There has been a good deal of turnover in the B & W technical group and we are not in as good a position to assess them as in the C E case.

STEINMULLER

While all those prepared to participate, have fully proven low NOx burners, Steinmuller appears to be in the best position in terms of limestone injection experience. They are prepared to work with a Canadian firm and Volcano report having had discussions with them.

Dr. Chughtai made a special trip from Germany to attend the baseline tests, met G. A. Robb Associates on the plane to Fredericton, provided more or less continuous assistance through the test period and went to Ottawa to provide information about his firm's experience with low

NOx burners and limestone injection.

Following successful pilot plant tests, SM burners were installed in a 700 MWe coal fired power station in 1978. A 50% reduction in NOx emissions was achieved without detriment to combustion.

Successful experiments by Rheinisch-Wetfalische Electrizaritswerke (RWE) with calcium-based sorbent addition to lignite for SO₂ absorption during combustion and earlier experimental work with bituminous coal in the sixties have contributed to development of an NOx/SOx absorption system.

Simultaneous reduction of NOx and SOx emissions with a prototype SM burner has been investigated with the International Flame Research Foundation in Holland. The results of this work have been published by Steinmuller. They have also had the burner tested by EER at the Santa Anna, California test facility.

Currently Steinmuller have underway, a demonstration in a 700 MWe coal fired boiler to determine desulphurization rate and define operating problems under field conditions. By the time the Gagetown experiments are underway, it would appear that Steinmuller will have far more operating experience than anyone else with a system injecting calcium based sorbents into a low NOx burner to

achieve simultaneous NO_x/SO_x emissions reduction.

The Flame Research Institute experiments demonstrated up to 80% SO₂ capture with high sulphur coal using calcium hydroxide with a Ca/S ratio of 2.5. This is considerably better than has been achieved with limestone but the calcium hydroxide is considerably more expensive. Fuel for calcining has become the dominant cost factor in calcium oxide and calcium hydroxide production where oil is the kiln fuel. If a less expensive fuel can be found for the kiln, the cost could be much less.

Steinmuller has found that SO₂ absorption is better when the sorbent is injected with secondary or tertiary air, not with the fuel. Bypassing the highest temperature zones avoid dissociation of calcium sulphur compounds and "dead burning" (loss of reactivity) of lime.

Apparently Steinmuller is keenly interested in the Gagetown experiments because they have been looking for a small pulverized coal boiler for further experimenting with their low NO_x/SO_x system. Only 2, of the many burners in the utility boiler they are using, are equipped for sorbent injection. More can be learned about certain aspects by fully equipping a small boiler as at Gagetown.

It seems clear that Steinmuller's interest in Gagetown is largely scientific. While using their know how, possibly under licence, would benefit Canadian boiler builders there

does not seem to be much a risk that Steinmuller will become a competitor in the Canadian Market.

If the Gagetown experiments are used to build on Steinmuller experience, Canadian boiler suppliers could learn a great deal whether or not they become involved with Steinmuller. Steinmuller appear to have in depth experience with NOx/SOx reduction using low NOx burners with limestone injection.

Steinmuller has a fully proven low NOx burner, the SM burner which uses tertiary air ports. They have worked with a large German utility in developing a combined NOx/SOx control system using the low NOx burner with limestone, calcium hydroxide and other sorbents injected into the furnace. They are willing to quote on a complete burner limestone system and have provided a budget price.

Steinmuller has assigned Dr. Herberholz and Dr. Chughtai to the project. Dr. Chughtai attended the baseline tests both with and without limestone injection and visited the Combustion Lab. for discussions with G. K. Lee.

COMBUSTION ENGINEERING

Combustion Engineering supply a great many boilers using tangential firing and are less oriented toward wall

type burners than the other suppliers. The Canadian Company has supplied a few wall type burners mostly with older boilers. The U. S. parent and the Japanese affiliate do use wall type burners and Combustion is definitely interested in the Gagetown experiments

Tangential firing tends to be inherently better than wall firing in terms of NOx emissions. Combustion are leaders in NOx control but mainly using tangential firing. Their Japanese affiliate use wall type burners to some extent as does the American parent but the Combustion group are basically advocates of tangential firing. Nevertheless C E Canada have expressed a keen interest in the Gagetown experiments. They built the Gagetown boilers and that is an advantage.

According to Dave Winship, Chief Engineer, the Combustion group are working with limestone injection and have had a good deal of experience in the past. We have not yet learned as much about what they have been doing as we have about Steinmuller because the American firms are less inclined to share their knowledge. C E claims that C E and Steinmuller are the leaders in low NOx/SOx technology

C. E. Canada helped with the baseline tests (Al Altman attended). They have a relatively strong technical group in Canada and would probably do more of the scientific and engineering work in Canada. Whereas our Foster Wheeler

technical contacts have been mainly with Livingstone, our C E contacts have been entirely with the Canadian firm. C E Canada should be given an opportunity to bid. Dave Winship, C E's Chief Engineer, has demonstrated a keen personal interest.

Dave Winship, spent a good deal of time explaining what they have done with both low NOx burners and limestone injection. Al Altman has been assigned to the project and attended the baseline tests

Foster Wheeler, Steinmuller, Combustion Engineering and B & W Canada all attended the baseline tests, are generally familiar with the boiler to be used for the experiments and are prepared to compete for the opportunity to participate in the project.

We have concluded that material suitable for pneumatic handling should be used at least for the experiments.

Advancement of NOx/SOx control technology should be the dominant consideration. The technology must be imported in all cases. The fact that Steinmuller has the most applicable experience and made one of their top researchers (a man very much involved in their NOx/SOx program) available for most of the baseline test period puts them in an excellent position to help with the Gagetown project.

Because he is currently involved in the German test program, Dr Chughtai was in a better position than anyone else to help. He was very helpful and seems willing to share his know how. He did not appear to be concerned about helping the competition.

The other firms expressed some concern about competition from Steinmuller if the Gagetown project were to be undertaken by them. Steinmuller appear to be motivated almost entirely by a desire to advance the technology because they consider it to be of great importance in their established markets - particularly Europe.

All 4 firms should be considered without bias. The fact that Steinmuller do not have a Canadian subsidiary should not be a consideration in this case.

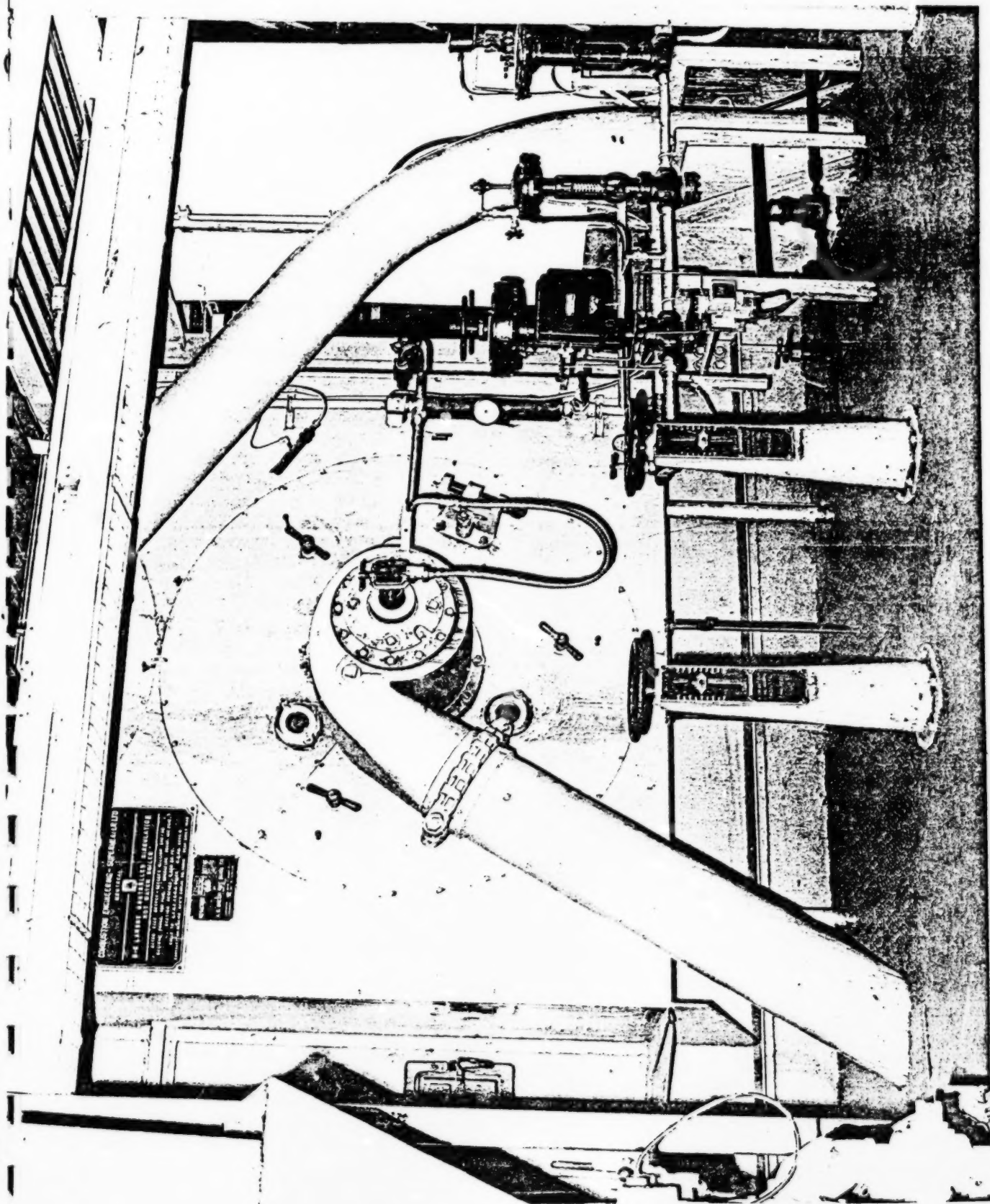
The Gagetown project should be based on the best available know how rather than an expensive learning experience to benefit firms with marginal experience in this complex technology. A proven low NOx burner should be teamed with a proven limestone injection system so it will be possible to concentrate on the limestone/burner interface. All 4 firms should be required to demonstrate this capability.

BASELINE TESTS AT CFB GAGETOWN

These will be the subject of a further report. They were carried out March 25 through March 31. The NO_x levels were consistent with those of the previous test and a good set of baseline data were obtained. SO_x levels were reduced some 40% by feeding limestone with the coal using feeders devised by Mr. Pollitt.

Limestone quantities were measured by counting the number of bags per hour so a good estimate of Ca/S ratio can be calculated when the coal and limestone analysis is available. Some information about limestone feedrates and a preliminary estimate of Ca/S ratio follows in Appendix 1.





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APPENDIX 1

CFB BASELINE TESTS, LIMESTONE FEEDRATES, MAR 29 & 30/82

MAR 29 (MON.) FULL LOAD MORNING, HALF LOAD AFTERNOON

Started limestone feed procedure at 4 AM but limestone feeder for upper mill would not feed. Initial half inch cones in feeders had small pieces of copper pipe welded to them this proved detrimental. Upper mill feeder cone replaced with 9/16 cone in attempt to make it feed. Solution proved to be introduction of conveying air but 9/16 cone left in place for duration of full load test on Mar 29.

Lower burner orifice had small piece of copper pipe left on for duration of full load test. This produced feedrates of 970 lbs per hour for the upper mill from 8 AM to 10 AM and 881 lbs per hour from 10 AM to 11 AM. The feedrate for the lower mill was 529 lbs per hour for the duration of the full load test from 8 AM to 11 AM

The total feedrate for the full load test from 8 AM to 10 AM was 1499 lbs per hour. From 10 AM to 11 AM it was 1410 lbs per hour.

The reason for the change in feed rate for a given cone orifice size, was changes in the mill draft- ie. the change in magnitude of negative pressure in the mill (pulverizer).

The load during the Mar 29 full load test varied between 18.1 MW and 19 MW but remained within 0.2 MW of 18.5 MW most of the time. Of 12 readings taken every 15 minutes from 8 AM to 11 AM all but 4 were within .2 MW of 18.5 MW. Thus, for purposes of this test the load can be considered to be 18.5 MW..

The temperature of the gas leaving the air heater increased from 486F at 8 AM to 516F at the end of the test. This was due to buildup of slag which appeared to be mostly

limestone on the back wall of the furnace and some (less) deposit on the side walls of the furnace. This means there was a gradual decrease in efficiency over time. Starting at 8 AM at fifteen minute intervals, the gas leaving the air heater was: 486F, 490F, 495F, 498F, ...F, 504F, 505F, 506F, ...F, 511F, ...F, 516F(11AM)

The air temperature entering the air heater was about 80 F. The Bailey temperature indicators were reading high. Because of this, a pyrometer which had been checked against 2 Environment Canada temperature indicators was used to measure the temperature of the gas leaving the air heater.

The Bailey oxygen analyser which indicates on a wet basis was checked against the Environment Canada indicator which was temporarily installed at the air heater outlet. The Environment Canada indicator, which is on a dry basis, read 0.2% lower than the Bailey indicator. The Bailey instrument should read lower because it measures on a wet basis, but not by very much. For test purposes the Bailey reading less 0.2% is used.

HALF LOAD TEST, MAR 29 AFTERNOON

The lower mill only was used for the half load test. The cone was changed to eliminate the piece of copper pipe. The orifice diameter was one half inch. The flow rate was 801 lbs per hour until about 3.00 PM and decreased to 793 by 3.30 PM and to 704 lbs/hour by 4 PM. The changes were due to a decrease in mill draft (less negative pressure in mill-ie. less mill vacuum).

FULL LOAD TEST TUESDAY MAR 30

Limestone feeding efforts started at 4 AM and the aim was to have 1/2 inch cones in both feeders. Due to problems with the feeder for the upper mill, a 9/16 orifice was used until about 10 AM when a 1/2 inch cone was installed. The feedrate was 881 lbs per hour until 10 AM and 559 lbs per hour with little variation after that. The lower mill feedrate was 752 lbs per hour with very little variation from 9 AM until the end of the test at 4 PM. Thus the total

feedrate was 1633 lbs per hour from until 10 AM and 1311 after that until the end of the test at 4 PM.

The upper mill tripped at 12.46 but apart from that the feedrate was roughly constant from 10 AM to 4 PM.

Ca/S Mole Ratio for Test on Blr 3 on Mar 30 from 2 PM to 4 PM (Full Load)

Limestone feedrate=1633 lb/hr Output=20 MW=68.26 MBTU/hr

Period of oil integrator readings= 101 min = 1.683 hr

Oil= 9811.5-9513.5= 298 litres Oil Flow= 38.94 Imp G/hr

Oil Calorific Value=.165 MBTU/Imp Gal

Oil Power Input = 6.425 MBTU/hr

Assuming the oil is Fuel Oil 9040 and calculating the "oil efficiency" from "A Combustion Handbook for Canadian Fuels":

Gas Temp. leaving Air Heater= 516 F

Air Temp. entering AH= 75 F

Assumed Excess Air = 15%

Dry Gas Loss= 9.0%

Hydrogen Loss= 7.0%

Radiation Loss= 0.8%

Unmeasured Losses= 0.5%

"Oil Efficiency"= 82.7%

Output from Oil= 6.425(.827)= 5.314 MBTU/hr

Output from Coal= 68.26 - 5.314= 62.946 MBTU/hr

Assuming the coal is Dominion No 20, Devco and calculating the "coal efficiency" from "A Combustion Handbook for Canadian Fuels":

AH temperatures as above

Flue Gas Oxygen= 4.56%

Oxygen from Oil (15% excess air)= 2.9%

Oxygen from Coal= (4.56x68.26 - 2.9x5.314)/62.946= 4.7%

Coal Dry Gas Loss= 10.6%

Hydrogen Loss= 4.05%

Assumed Moisture Loss= 0.7%

Unmeasured Losses= 0.5%

Radiation Loss= 0.8%

Coal Efficiency= 83.35%

Coal Input= 62.946/.8335= 75.52 MBTU/hr

Assumed Coal Calorific Value=0.0136 MBTU/lb

Coal Flow= 5553 lb/hr

Sulphur= 2.6% by wt.

Sulphur Flow= 144.4 lb/hr

Atomic Wt. of S= 32

Moles of Sulphur per hour= 144.4/32= 4.5

Atomic Wt. of CaCO₃= 40+12+(3x16)= 100

CaCO₃ Flow (Assuming 90% CaCO₃ feed)= .9(1633)=1470 lb/hr

Moles of Ca per hour= 1470/100= 14.7

Ca/s Ratio= 14.7/4.5 = 3.26

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APPENDIX 2

THE EER REPORT ON LOW NO_x BURNERS WITH LIMESTONE INJECTION
FOR CANADIAN FORCES BASE - GAGETOWN, OREMOCTO NB
REVIEW AND EVALUATION

INTRODUCTION

Industrial steam plants in the Atlantic provinces burn about as much fossil fuel as do the utilities and as the oil price increases coal becomes an increasingly attractive alternative for industrial steam plants. Coal is now a basic industrial boiler fuel in Ontario.

Nova Scotia and New Brunswick coals and a great deal of the coal produced in eastern USA have relatively high sulphur levels. While U. S. and western Canadian low sulphur coals are available in eastern Canada, the price is higher than for the higher sulphur U. S. coals. This significant price difference combines with the desire to use Maritime coal to help justify efforts to reduce SO_x emissions with the higher sulphur coals.

The CFB Gagetown boilers are roughly the size of many industrial boilers. District heating using boilers in this size range may be used in the future. Burners designed for utility boilers tend to have flames too long for industrial size boilers. As well, the burners used in the Gagetown experiments can be scaled up for utility use. Gagetown provides an excellent opportunity for evaluating wall type low NO_x burners with limestone injection whether the burners are being developed for heating boilers, industrial boilers or utility boilers.

B & W and Foster Wheeler have noted that they tend to use stokers for coal fired industrial boilers up to 200 MBTU/hr but both have supplied many industrial boilers for pulverized coal firing in the past. Lower electrical costs in Canada argue for pulverized coal for smaller units and Combustion Engineering prefer the pulverized route. In any case most of the industrial boiler potential relates to

retrofitting existing boilers. The fact that the boiler builders feel the Gagetown experiments will help with utility burner development is important.

Energy and Environmental Research Corp. of Santa Ana, California were retained to develop a proposal for research into NOxSOx reduction using the CBF Gagetown boilers. Their report is very valuable in terms of scientific content. The approach they proposed involved a major development program in their own lab. Instead of the installation of proven burners directly in the Gagetown boilers. They offered to serve as prime contractors and project managers as well as technical advisors. Their proposal involved a percentage of everything for them. With this sort of approach there is clearly a conflict of interest because the more the project costs the more they earn.

It has been decided that fully proven burners should be installed in the Gagetown boilers, there should be no U. S. development program funded by EMR/CANMET and EER should not be the project managers. Thus, these aspects of the report are not dealt with here. The value of the report is largely limited to the information about sources of technology, the scientific content and the suitability of the Gagetown boilers for experimental work. These aspects are reviewed in what follows.

GAGETOWN FACILITIES

There are 3-hot water generating units, each with two-35MBTU/hr, CE front-wall circular pulverized coal burners. Two of the 3 boilers are used in winter and the third is required as standby. Thus the low NOx burners must be fully proven in terms of ability to maintain a stable flame. Three percent sulphur Cape Breton coal is burned but, because of flame stability problems at low load, oil support is used at all times.

The small furnaces have low heat liberation rates (half to a sixth that of large boilers) and hence lower temperatures which is better for NOx control. The furnace dimensions of 16 X 10 ft should be adequate to contain the burner flame proposed by EER and Foster Wheeler, though the windbox would have to be deepened to accomodate tertiary air. Each burner is served by separate Raymond bowl mill

pulverizer. Boiler no. 2 has been selected for the experiments.

NITROGEN OXIDE CONTROL

The term fuel NO_x is used to describe nitrogen oxide arising from nitrogen in the fuel. This is important with coal. Nitrogen oxide formed when nitrogen from air combines with oxygen is termed thermal NO_x.

Fuel NO_x is minimized by driving the majority of the compounds into the gas phase under fuel rich conditions and providing a stoichiometry - temperature history which maximizes decay of gaseous nitrogen compounds to nitrogen.

Thermal NO_x is formed where there is both high temperature and excess air - ie. if there is a high temperature oxidizing zone. Thermal NO_x formation is reduced via two or three stage combustion where the first phase is in a high temperature reducing zone and the last phase is in a lower temperature oxidizing zone. NO_x does not tend to be formed in the first stage because the available oxygen reacts preferentially with carbon and there is no surplus to react with nitrogen. In the final oxidizing phase the reduction in temperature reduces the tendency for oxygen to combine with nitrogen.

The distributed mix, front wall burner provides for three zones of combustion. In the first zone, pulverized coal transported by primary air, combines with inner secondary air and ignites to form a very fuel rich recirculation zone (30 to 50% stoichiometric) which provides flame stability. Volatiles are driven off and fuel nitrogen compounds are released into the gas phase. Outer secondary air is added in a second 70% stoichiometric zone. This is the optimum zone for reduction of nitrogen compounds to nitrogen. Air to complete the combustion in a relatively low temperature third zone, about 20% excess air (i.e. 120% stoichiometric), is added through tertiary air ports located outside the burner throat.

EER provides status reports on 4 of these distributed mix (DMB) burner developments. The EER/Foster Wheeler

controlled flow burner has an annular/tangential inlet, primary nozzle & dual secondary air passages. It has passed research furnace tests at full scale. Measured NOx was 0.2 lbs/million BTU. This burner is now in commercial use in a Wisconsin Power Co. boiler (EPA contract no 68-02-3127) but EER are working on improvements. The EER proposal is based on a slightly modified version.

The Steinmuller staged mixing burner has an annular primary air nozzle and a single secondary air passage. Field tests indicated 0.4 lb NOx/million BTU. B & W (USA) have a dual register burner with dual secondary air passages and EER are working on a DMB which they say emitted 0.1 lb NOx million BTU when tested in a research furnace. Apart from the EER report, B & W have noted that they are using their dual register DMB burner at the Ontario Hydro Atikokan coal fired steam - electric station. They are working on an industrial version.

SULPHUR OXIDE CONTROL

According to EER, recent experimental evidence suggests that the low temperature reducing furnace conditions produced by the DMB flame are ideal for the reaction of sulphur compounds with sorbents such as limestone. Reductions of up to 80% of uncontrolled SOx emissions are indicated.

Most of the experimental work has been done with limestone but there is some evidence to suggest that calcium hydroxide is more effective than calcium carbonate. It seems clear that a good deal more experimental work is required to determine the best approach to sorbent injection at the burner and to evaluate the effect.

The U. S. EPA is conducting R & D to determine whether conditions produced by the DMB are conducive to sulphur oxide removal by sorbent injections at the burner.

The limestone can be mixed with the coal before the pulverizer or it can be injected with one of the combustion air streams (secondary or tertiary). The limestone calcines to calcium oxide in the furnace and the calcium oxide reacts

with SO_x to form compounds which remain in the ash.

It is known that the reactivity of the calcium oxide is reduced by high temperature. Thus, the DMB concept which reduces peak flame temperatures could provide a highly reactive environment. The case for injecting the limestone with the secondary or tertiary combustion air is founded on the argument that this bypasses the higher temperature zone.

According to the EER report, in the optimized NO_x/SO_x concept, the reducing zone dimensions are extended and the temperature is controlled by heat extraction before air is added for burnout. "Sorbent injection into the optimized system would be directly into the reducing zone, most likely with the coal".

Because there is no excess air and hence less cooling, it can be argued that the reducing zone in a DMB burner is at a higher temperature than in a conventional burner and hence there is more risk of loss of reactivity if the limestone is mixed with the coal with phased combustion than with conventional combustion. If that is the case, the solution is to add the limestone with secondary or tertiary air. The risk of loss of reactivity would appear to be least if the limestone is added with the tertiary air.

The EER report is not conclusive as to the best way to add the limestone.

Coal sulphur is divided into two classes - organic and inorganic. Organic sulphur consists of metal sulphides (pyritic sulphur) and sulphates. Organic sulphur refers to all sulphur which is bound to the hydrocarbon matrix.

Inorganic sulphur can be washed out. Organic sulphur will be evolved from coal during devolatilization and will form hydrogen sulphide which will be oxidized to sulphur dioxide if oxygen is present. The calcined limestone reacts with sulphur dioxide to form calcium sulphite or calcium sulphate. The chemical reactions are, according to the EER report, different under reducing conditions. In that case sulphur is in the form of H₂S. The CaO reacts with H₂S to

form CaS plus water. The report concedes that very little is known about the chemistry of the reducing zone.

The EER report discusses the result of a number of experiments where limestone, calcium hydroxide, calcium oxide etc. have been injected at the burner. The experimental evidence argues for Ca/S molar ratios between 2 and 4.

At 2 the sorbent seems to capture between 25% and 60%. At 3, between 40% and 75% At 4 up to 80% is captured. The results indicate that a good deal more experimental work is required.

Comment

The EER report deals at length with the effectiveness of sulphur absorption in various zones in the furnace. It does not appear to deal with the possibility that additional sulphur may be absorbed downstream of the furnace. There will be a lot of particulate/gas interaction in the dust collector for example. There will no doubt be a good deal of lime (calcium oxide), from when the limestone calcines in the furnace, in the particulate because only a fraction will have reacted with sulphur in the furnace. Lime has been effective in dry scrubbing systems whereas limestone has not. It would be interesting to explore the possibility of using the excess lime in the particulate as a reagent for dry scrubbing and combine the two techniques. The EER report does mention the possibility of sulphur absorption by particulate after the furnace in discussing the proposed field measurement system.

EMISSION MEASUREMENT AND FIELD TEST PLAN

The EER report deals at length with test procedures. The proposed field measurement systems would continuously monitor NO_x, oxygen, CO, carbondioxide, and sulphur dioxide. The fact that carbon dioxide is formed during the calcining process must obviously be taken into account.

There appears to be no mention of measuring NO and NO₂ separately. During selected tests there would be monitoring of SO₃ as well as SO₂.

There is a good deal of discussion of sensing devices and EER experience with the various types.

The field test plan calls for a period of experiments to establish optimum conditions followed by 30 day tests at optimum conditions to verify performance and emissions measurements. This it, is said, will provide data comparable to boiler measurements made by the U. S. EPA. to determine whether new source performance standards are being met.

These tests involve continuous monitoring of gaseous emissions and boiler load. NO_x emissions will be monitored at various levels of excess air & load, distributions of primary, secondary and tertiary air to the burners and at various burner settings.

Flow rate and composition of both flyash (particulate) and bottom ash are to be determined during selected tests. This appears to mean total particulate leaving the boiler. The bottom ash flow rate would be determined by difference.

APPARENT ABSENCE OF FINANCIAL ANALYSIS OR JUSTIFICATION

There does not appear to be any attempt at financial analysis or discussion of the case for injection of sorbents at the burner as opposed to say, dry scrubbing. The optimum level of limestone feeding would depend on the cost of the limestone. In this report the term optimum appears to have been used in a purely technical sense. The term feasibility also appears to be used in a narrow technical sense.

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APPENDIX 3

INFORMATION ON LIMESTONE AND OTHER CALCIUM BASED PRODUCTS
AVAILABLE FROM HAVELOCK LIME, HAVELOCK, NEW BRUNSWICK

Havelock is within trucking distance of CFB Gagetown. The firm has a good reputation. They are equipped to crush and screen limestone for delivery by dump truck. They are also equipped to dry and size crushed limestone for pneumatic handling using screens for courser material and an air classifier for fine material.

They estimate that the 100 mesh or less material contains at least 50% 200 mesh or less material. The equipment they have now can not produce pure 200 mesh or less material. To produce 100 or less they use a grinder followed by an air classifier. They say that to produce pure 200 or less material, a \$500,000 new air classifier would be required. They have undertaken to have the 100 or less material tested to find out how much 200 or less

material it contains.

Calcium oxide is available at about \$60 per ton plus \$14 per ton transportation- ie. \$74 per ton. Calcium hydroxide is now price at about \$69 per ton plus transportation- ie \$83 per ton. In the case of calcium hydroxide, 98% passes a 200 mesh screen and most is smaller.

Before the oil price increase, calcium hydroxide was priced at \$20 per ton. The cost of either calcium oxide or calcium hydroxide is largely due to the price of oil for the kiln used for calcining. If a cheaper fuel could be found the material would cost less.

Following are prices as of early 1982:

CRUSHED LIMESTONE SCREENED BUT NOT DRIED

PARTICLE SIZE	MATERIAL	TRANSPORTATION
	COST	COST
	\$/METRIC TON	\$/METRIC TON
1.25" OR LESS	\$9.20-\$9.60	\$8.80
1.25" TO 0.75"	" "	"
0.75" TO 0.25"	" "	"
0.625" TO 0.25"	" "	"
0.50" TO 0.25"	" "	"
LESS THAN 0.25"	\$5.60	"

None of the above can be handled pneumatically

Less than 0.25" contains dust - a problem when wet

HIGH CALCIUM SCREENED AND DRIED - DELIVERED BY TANK TRUCK
EQUIPPED FOR PNEUMATIC UNLOADING TO 60 FT UP

MESH AND PARTICLE SIZE		MATERIAL COST	TRANSPORTATION COST TANK TRUCK
PASSES max	RETAINED min. size particle		
6 MESH	16 MESH	\$20.20	\$14.00 (COURSE NO DUST)
16 OR LESS		15.60	14.00 (INCLUDES DUST)
16	100	17.60	14.00
100 OR LESS		23.80	14.00 (ALL DUST)

EACH TRUCK DELIVERS 30 TONS

Note - The 16 or less dried high calcium material costing
\$15.60 per ton for material and \$14 per ton for delivery or
\$29.60 per ton delivered is mostly dust and should be

suitable

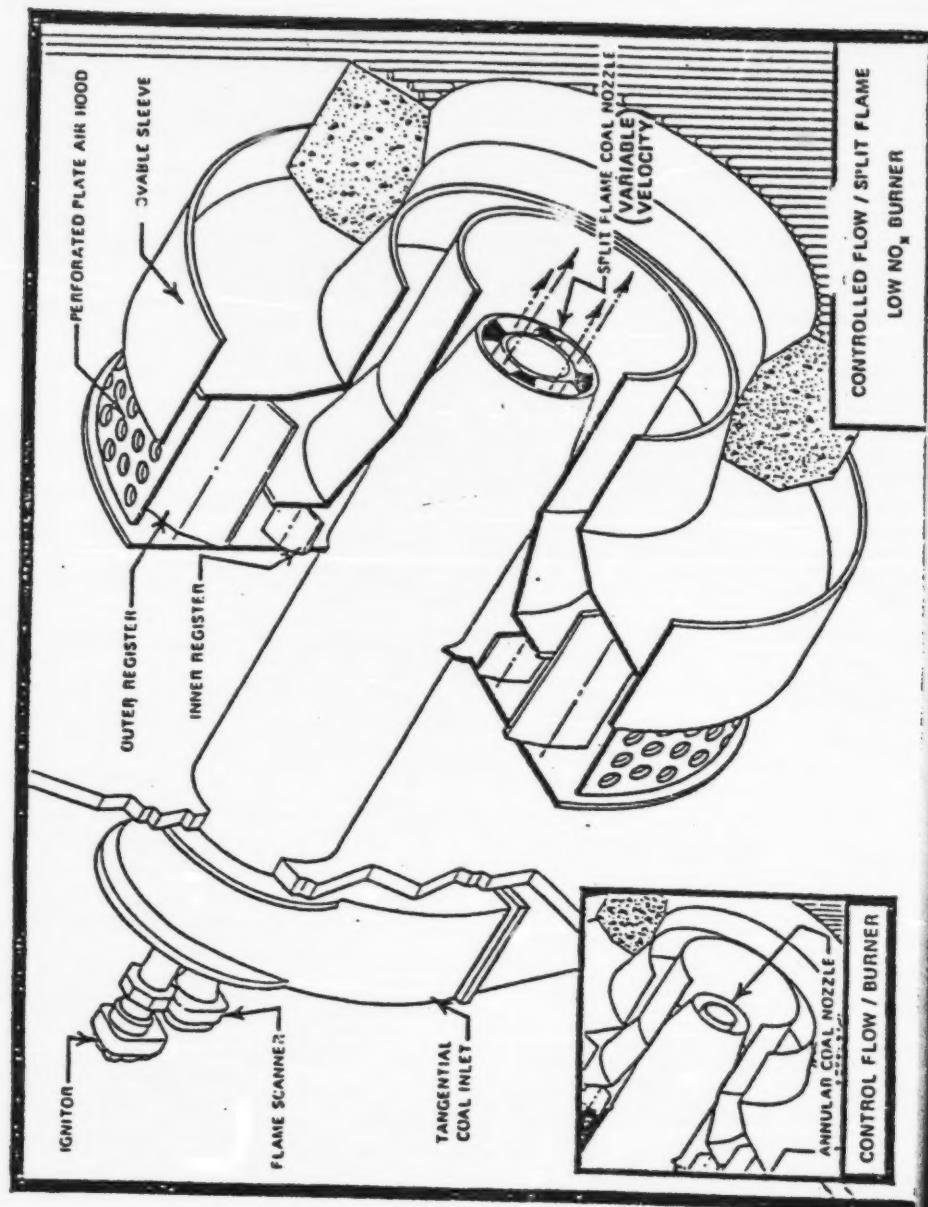
Havelock lime supplies pulp and paper mills, agriculture (lime for increasing soil alkalinity for chicken feed etc.) and other markets. It is a locally owned family firm employing a good many people. Equipment such as tank trucks is quite modern. They have a kiln for calcining, facilities for drying and screening etc. The road between Havelock and CFB Gagetown is good and the distance reasonable

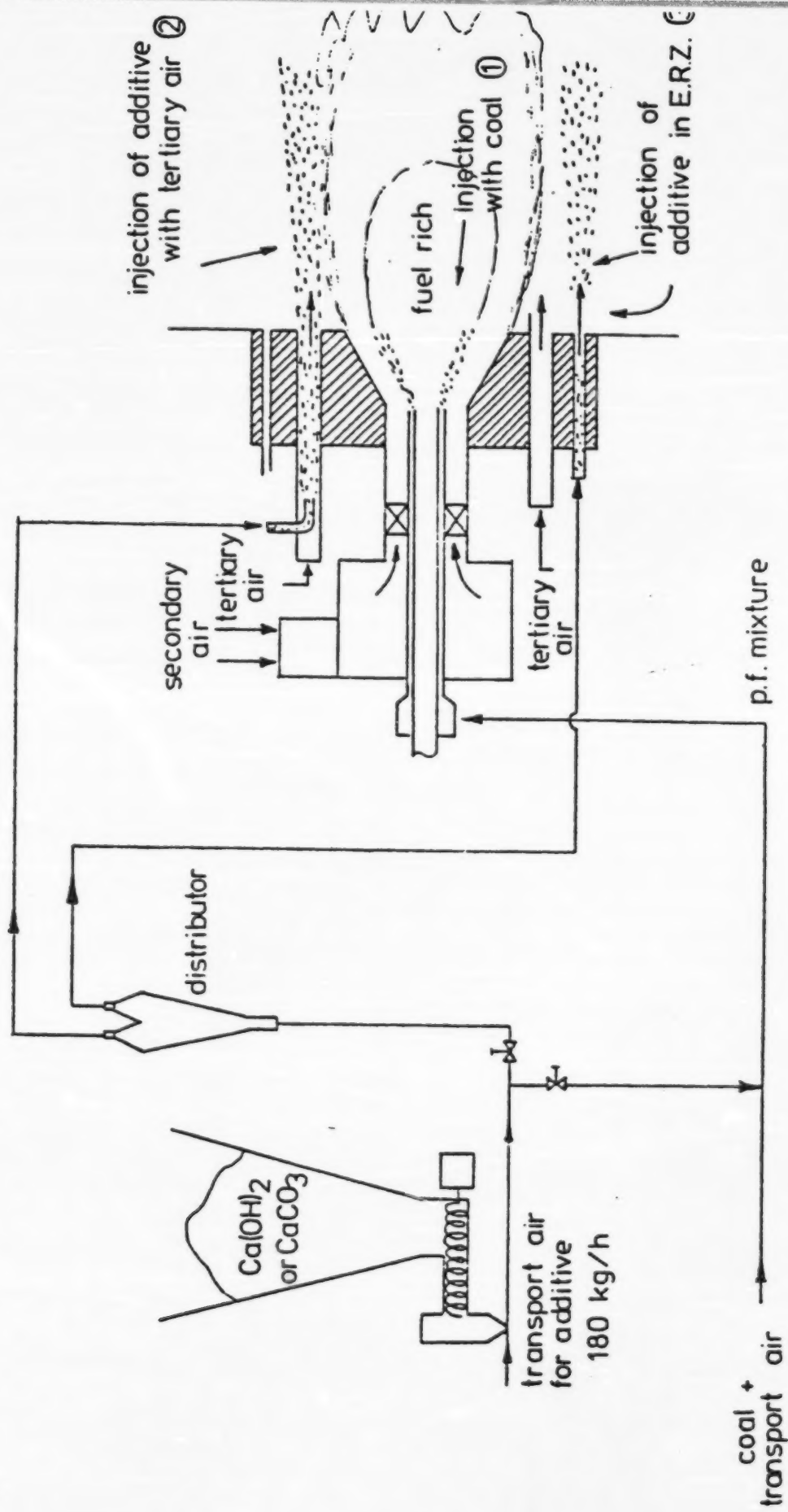
Mr. Gordon Thomas of Fredricton is an agent for Havelock Lime and has helped Mr. Pollitt. Both Mr. Thomas and the management of Havelock lime feel we would be better off using dried material which can be handled pneumatically.

At this stage and for the experimental period there is a case for dealing only with Havelock lime. If, after the experimental period is over, an alternative could be found, it might be considered if costs could be reduced.

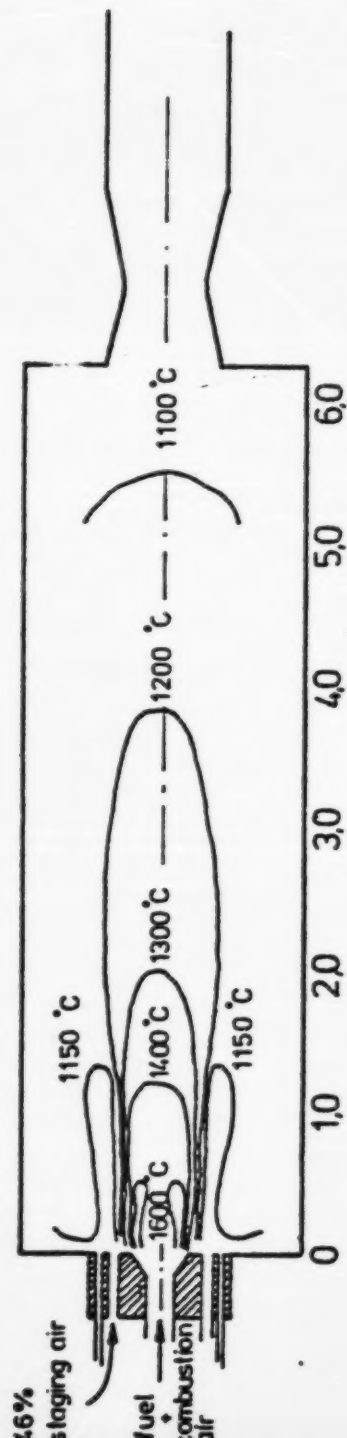
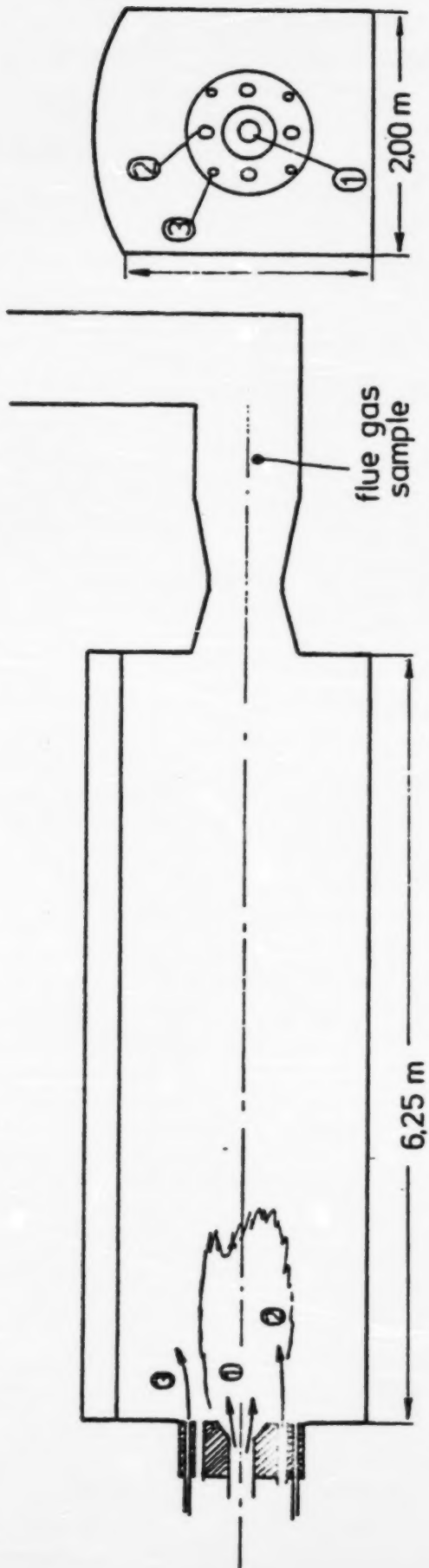
APPENDIX 4

FOSTER WHEELER

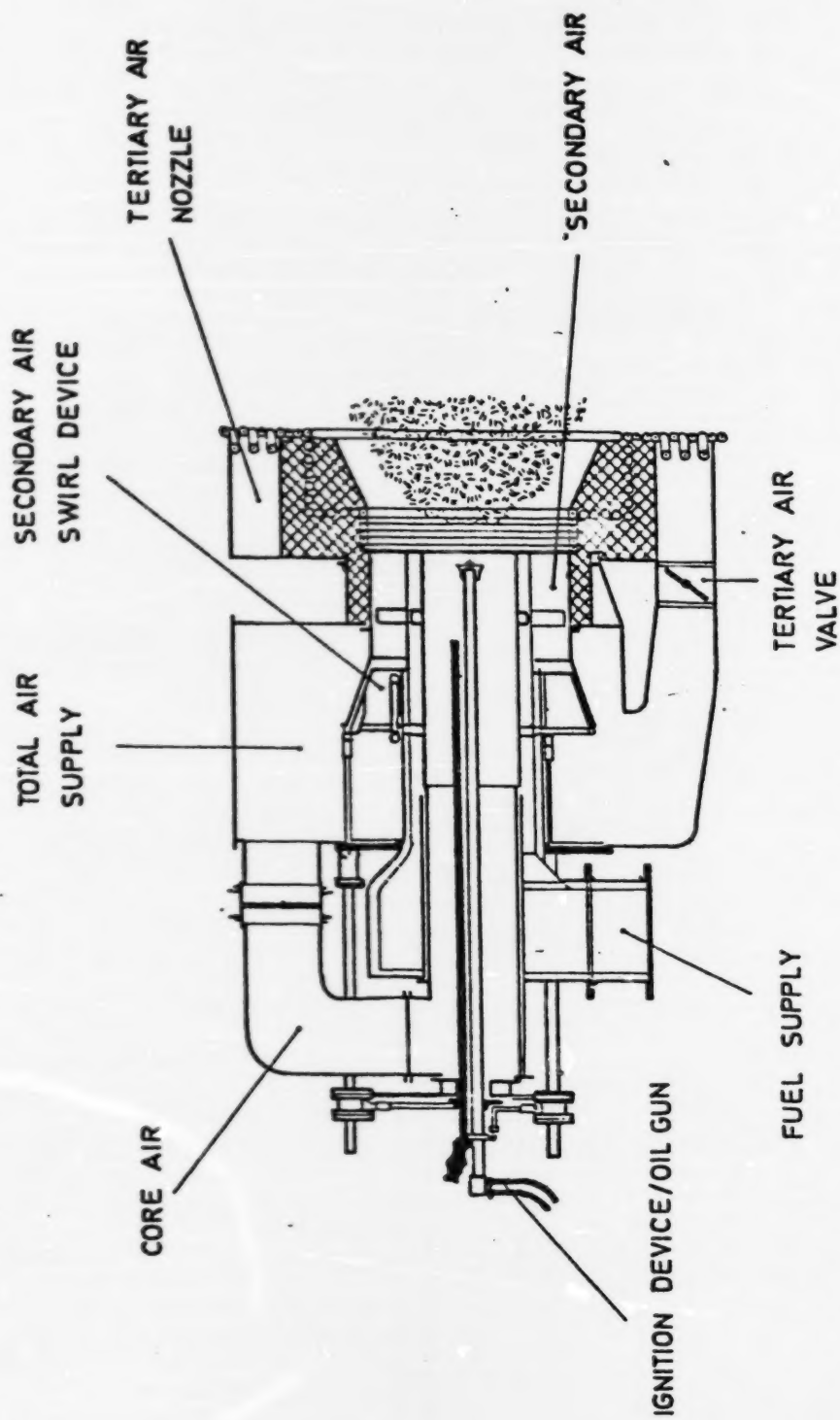




Schematic of various possibilities of
injection of the additive

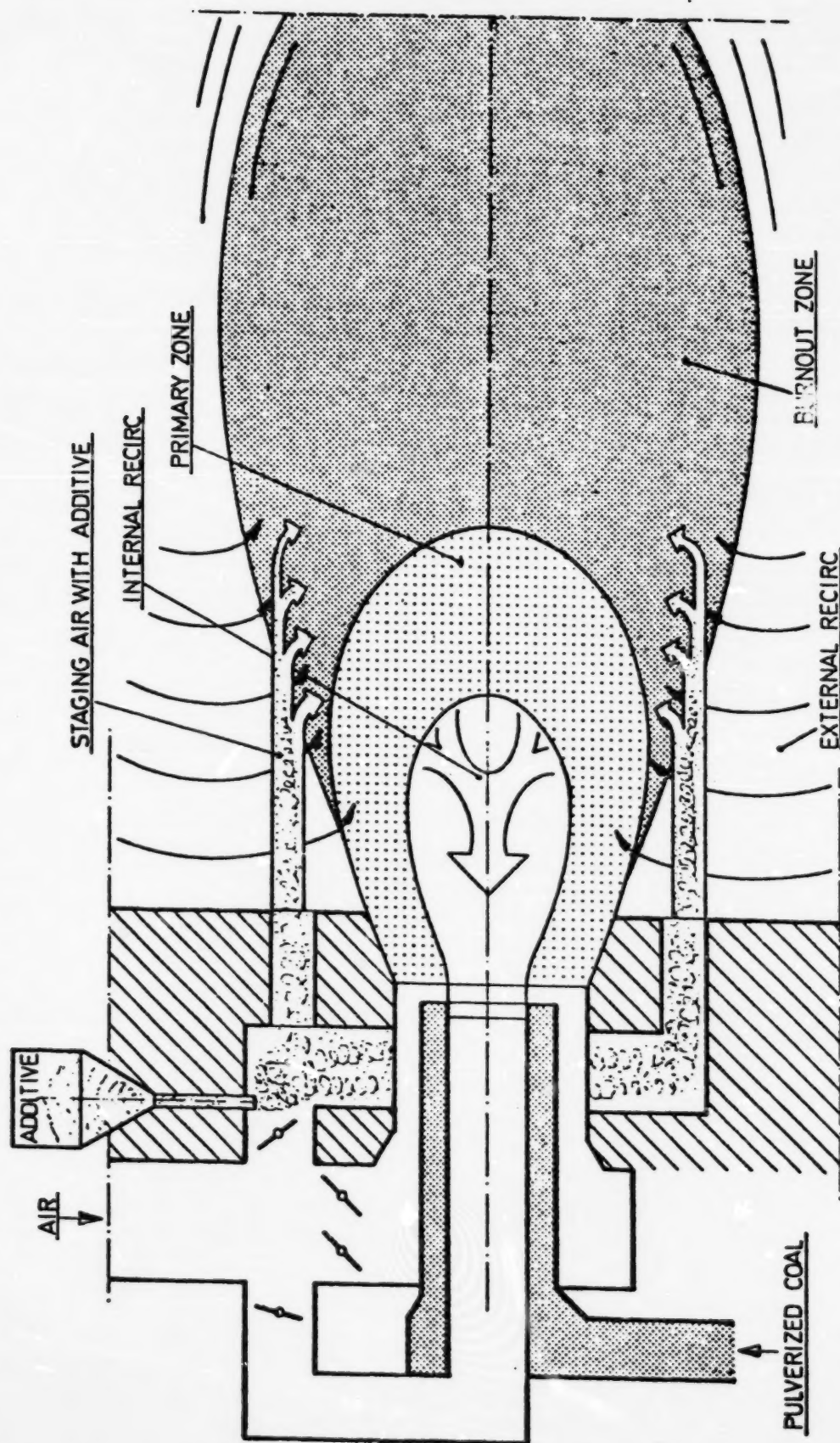


Schematic of IFRF furnace no. 1 with staged maxing burner
 localization of various sorbent injection possibilities and typical
 temperature levels measured with a 2.3 MW coal flame



Staged mixing burner for low NO_x and low SO_x

STEINMÜLLER



Working principle of staged mixing burner for low NO_x and low SO_x .

STEINMÜLLER

